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COMPOSITE THICKNESS OPTIMIZATION OF OFFSHORE WIND TURBINE BLADE WITH FIXED OUTER GEOMETRY

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Summary. With the objective of mass minimization, a 73-m offshore wind turbine blade is optimized using a gradient based approach on a Finite Element (FE) model. Constant loads and a fixed outer geometry are assumed. Plies of the same material and same orientation are grouped together in plygroups. The thicknesses of the plygroups are chosen as design variables. Manufacturing constraints such as ply-drops are taken into account using linear constraints. Structural constraints include buckling, tip displacement and max. strain failure indices.

1 INTRODUCTION

Offshore wind turbine blades are getting increasingly longer and heavier every year. These blades are often manufactured in big molds where the dry material is build up and solidified with resin using a vacuum process. The molds are relatively expensive, and a large number of blades needs to be manufactured in each mold before they are profitable. In the case of tailoring a blade for a new site with different loads, or simply redesigning a blade using improved design tools, changes to the outer geometry are not permitted as that would require changing the mold. In this work a proposed design method for minimizing the mass of an offshore wind turbine blade with a fixed outer geometry will be presented.

Mass minimization of wind turbine blades has been studied in a number of examples. In [1], a genetic optimization algorithm is used to find the optimal thickness of the shell and webs. However, the entire shell and web are assumed to have the same thickness. This is a consequence of genetic algorithms being very computationally expensive for many design variables. Another approach is used in [2] where a gradient based method called 'Discrete Material and Thickness Optimization' (DMTO) is used. In this method each layer has a density variable to determine if there should be material or not (topology). This is combined with multi-material optimization where each ply in addition also have material weight factors allowing it to 'choose' the best material. As this approach yields multiple design variables for each ply, it becomes computationally expensive for large structures.

In the following a parameterization with relatively few design variables will be presented. The parameterization approach will be demonstrated on a 73-m offshore wind turbine blade.

2 PARAMETERIZATION

The parameterization is done by first dividing the wind turbine blade into regions of similar layup. This can be seen on Figure 1 with the divisions marked using red dotted lines. Within these regions a constant layup is assumed.

Since wind turbine blades are often build up using many layers of the same material and same orientation, it is possible to group these together into plygroups. A sequence of these plygroups is assumed for each region. An example of a sequence of plygroups is shown on Figure 1 for the Main Laminate (MA) region. The thickness of the plygroups are the design variables used in the optimization problem.

The wind turbine blade is divided longitudinally into sections. In this work the sections have a length of 2 m. The thickness of a plygroup with unidirectional (UD) material located in the Main Laminate (MA) in longitudinal section no. j will be denoted $t_{MA,j,UD}$. The indices MA,j constitute what we denote as a patch: A group of finite elements with the same layup.

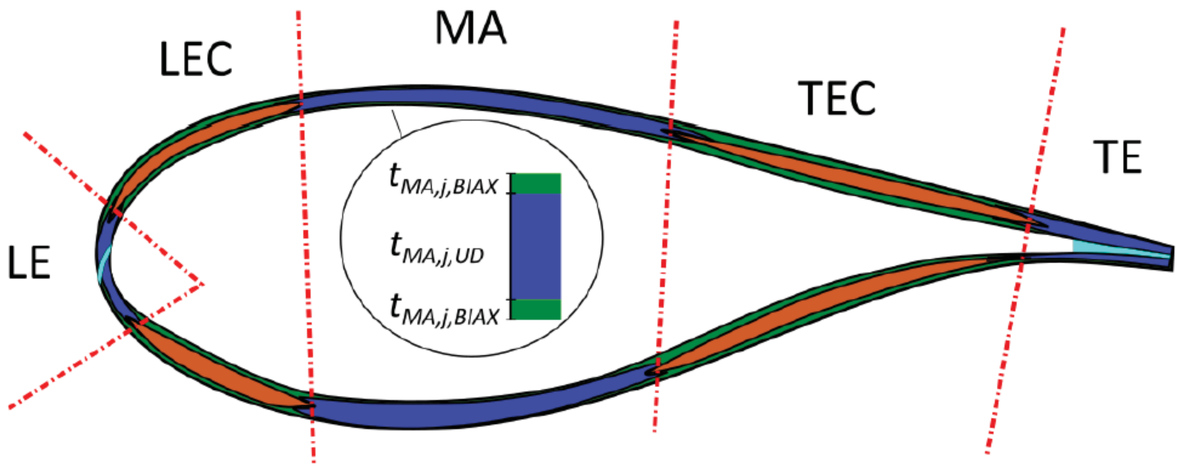

Figure 1 – Wind turbine blade cross section divided into regions of similar layup: Main Laminate (MA), Trailing Edge (TE), Trailing Edge Core (TEC), Leading Edge (LE), Leading Edge Core (LEC). Also shown is an example of the plygroups, and the sequence of plygroups, of the MA region.

2.1 Manufacturing Constraints

Plygroup thicknesses are allowed to vary independently as long as they are within manufacturing constraints. In this work ply-drop constraints are demonstrated. These are implemented by limiting the change in thickness in a plygroup from one patch to another. They are only applied in the longitudinal direction, and as an example they can for the MA UD plygroup be written as:

$$t_{MA,j,UD} - t_{MA,j+1,UD} \leq \text{p} \tag{1}$$

$$t_{MA,j+1,UD} - t_{MA,j,UD} \leq \text{p} \tag{2}$$

Here is p the allowable change in thickness per meter multiplied with the distance between the two longitudinal sections.

3 MODELLING AND METHOD

This work takes offset in the outer geometry of a 73-m offshore wind turbine blade. The full description of the layup is beyond this extended abstract, but is similar to what is seen on Figure 1. Design variables include the UD plygroup thicknesses in TE/LE/MA regions, and also the core thicknesses of the LEC/TEC regions are included.

3.1 Finite Element Model

The wind turbine blade is modelled using a FE model. The FE model is using layered solid-shell elements which is important in order to capture the correct stiffness in the trailing edge, see e.g. [3]. Furthermore solid-shell elements provide better results for the out-of-plane components. A cross-section of the FE model can be seen on Figure 2.

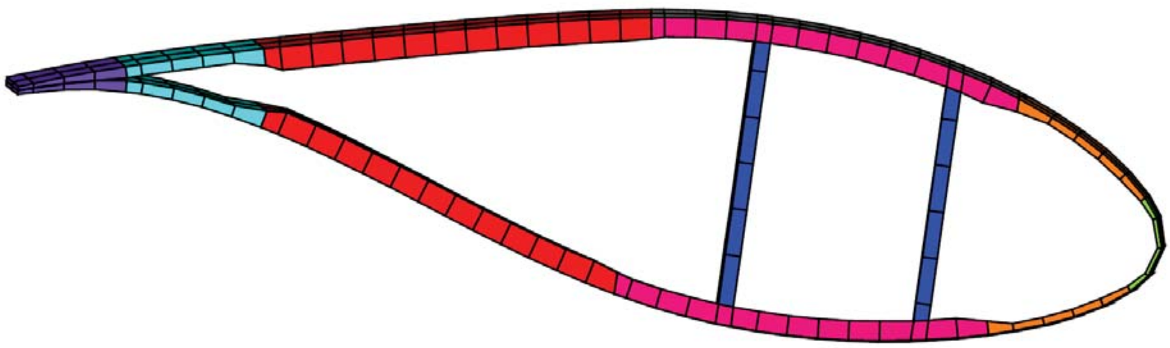

Figure 2 – A cross-section of the FE model. The blade is modelled using solid-shell elements, with one element through thickness. The different colors display the regions which the blade is divided into.

3.2 Optimization

The optimization problem is solved using a Sequential Linear Programming (SLP) approach. Sensitivities are found using a semi-analytic approach implemented in an in-house design and optimization tool called MUST [4]. The SLP approach is combined with merit functions, a global convergence filter and an adaptive move-limit strategy, see [2] for more details. The optimization objective is to minimize the mass of the blade using thickness design variables. Structural constraints are set up for both the edgewise and flapwise load cases and include linear buckling load factors, tip displacement and max. strain failure indices. Manufacturing constraints include plydrop constraints and upper/lower limits on thicknesses.

4 RESULTS

Optimization results are shown on Figure 3 where it can be seen that the mass of the blade is reduced from 30105 kg to 28825 kg. Normalized constraint values are also plotted and it can be seen that the buckling load factor and tip displacement in the flapwise load case are active constraints in the last iterations.

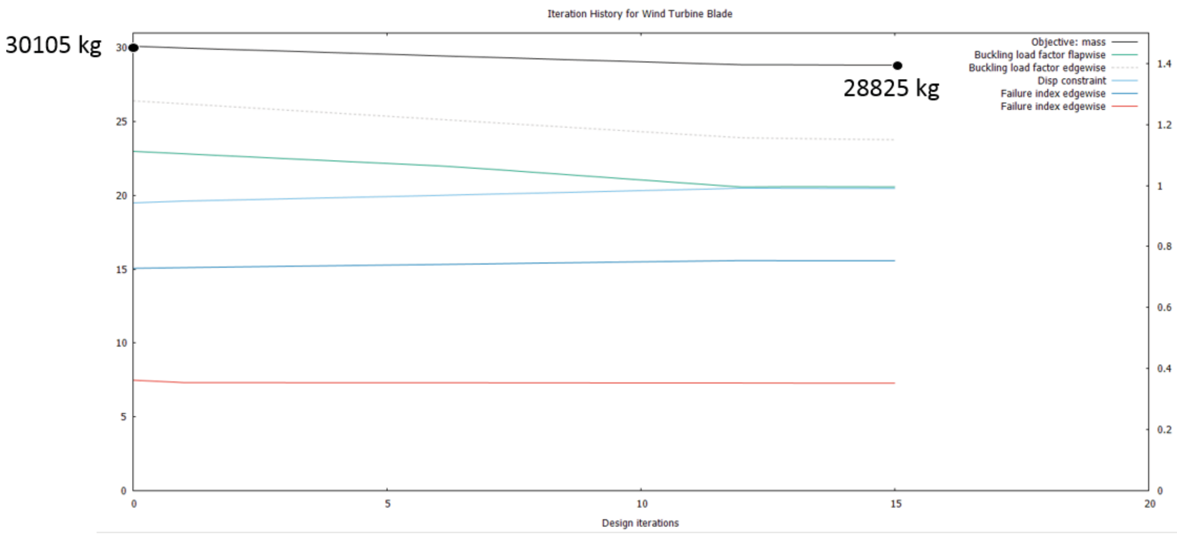

Figure 3 – Optimization results: On the left axis is the mass of the blade. On the right axis are normalised constraints.

5 CONCLUSIONS

A wind turbine blade design approach has been demonstrated. The design approach utilizes gradient based optimization to minimize the mass of the blade. Using two load cases and constraining linear buckling factors, tip displacement, failure indices and thickness changes, the mass of the blade is reduced from 30105 kg to 28825 kg.

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